



Muir Woods National Monument

Acoustic Monitoring Report

Summer 2005 and Winter 2006



Charlotte Formichella
Kurt Frstrup
Damon Joyce
Emma Lynch
Ericka Pilcher

NPS Natural Sounds Program
1201 Oakridge Drive, Suite 100
Fort Collins, CO 80525-5596

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Executive Summary

Management of acoustic resources at Muir Woods National Monument is mandated by the Organic Act, NPS policy and guidance, and park management plans. This park, managed by Golden Gate National Recreation Area, is affected by noise from a variety of sources including commercial and private aircraft overflights, maintenance and contractor activities, and large visitor use numbers. As stated in the San Francisco Bay Area Network's 2007 technical assistance request, the acoustic environment at Muir Woods may be one of the more important indicators for the quality of visitor experience and resource protection in the network. This national monument is home to several resident pairs of spotted owls, nesting and migrating birds, and many other animal species that rely on an intact old-growth forest. Noise, both ongoing and sudden, in certain parts of the forest, or at critical times of year, may affect the health of the forest's wildlife. Muir Woods is also directly under a commercial airline flight path where overflights seem to be increasing. The objectives of this report are to quantify existing acoustic conditions in Muir Woods National Monument, and provide results that can be used for park planning. Two years of monitoring data (summer and winter) from an acoustic monitoring site near the Hillside Trail were analyzed and are presented in this report.

The percent time audible metrics shown below indicate the amount of the 24 hour day that is affected by extrinsic and more specifically, aircraft sounds. Although they contributed significantly to the total audibility of extrinsic sounds, aircraft were not the most frequently audible extrinsic sounds at Muir Woods during these two monitoring periods. Rather, people talking and walking were the most commonly audible extrinsic sounds.

Interestingly, extrinsic sounds were audible more frequently in the winter than in the summer, even though the median daytime and nighttime existing ambient levels were higher in the winter. A number of factors probably contributed to this unanticipated trend. First, in the winter, there is likely to be less diffraction of sound by deciduous leaves, so sound will carry further. Second, cooler winter temperatures allow low frequency sounds (such as those generated by planes) to propagate further over the canyon walls. Third, the playback equipment used for winter analysis was superior to that used during summer analysis.

Considering that the noise floor (absolute sensitivity of the electronic components) of the acoustic monitoring system was about 16.5 dBA, the median night time existing ambient level in Muir Woods was very quiet during the summer (about 21 dBA). The winter existing ambient was considerably louder because of the presence of a nearby stream.

Site Location	<u>Mean % time audible^a</u>		<u>Median A-weighted Existing Ambient (L₅₀) in dBA^b</u>	
	Extrinsic sounds	Aircraft sounds	Day (0800-1900)	Night (2000-0700)
Hillside Trail Summer 2005	26.5	3.6	28.1	20.9
Hillside Trail Winter 2006	33.1	24.3	46.3	46.3

^a Over 24 hour period, based on off-site listening analysis.

^b For comparison, nighttime sound level in a typical residential area is about 40 dBA.

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield, 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature compelling reasons for visiting national parks (McDonald, Baumgartner, & Iachan, 1995). Acoustic monitoring provides a scientific basis for assessing the current status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions. In its 2001 *Management Policies* (NPS 2001), the National Park Service (NPS) identified natural and appropriate cultural sounds as a natural resource for parks to preserve, protect, and restore.

Each national park has a unique set of geologic, ecological, and vegetative attributes which determine its acoustic characteristics. Therefore, before managers can formulate management plans, they must first identify the current acoustic status and natural ambient sound levels of their respective parks. The San Francisco Bay Area Network (SFAN) Inventory and Monitoring (I&M) Program identified acoustic resources as a vital sign (a measurable feature of the environment which provides insights into changes in the state of the ecosystem) for the area. SFAN received support from the Pacific Coast Learning Center, Golden Gate National Parks Conservancy, and the Muir Woods Transportation Planning Project to carry out this study. Muir Woods National Monument (MUWO), managed under Golden Gate National Recreation Area, was selected to be the pilot test site for the development of acoustic inventories and monitoring within the network.

As stated in the Muir Woods Proclamation, the old growth forest is “of extraordinary interest and importance because of the primeval character of the forest... and the character, age and size of the trees...” (Muir Woods Proclamation 1908). At MUWO, the natural acoustic environment in the redwood forest is a vital park resource because it reflects this area’s “primeval character.” The park is currently revising its General Management Plan (GMP) and will use the results of this study to help visitors hear and appreciate the natural sounds of a redwood forest. Furthermore, the results of audibility analysis will show park managers the level, nature, and origin of natural and inappropriate sounds as they vary by season. In addition, the recordings will serve as permanent documentation of what Muir Woods sounded like in 2005 and 2006. The acoustic and sound pressure level data collection procedures in this pilot study are guided by the National Park Service Natural Sounds Program’s standards. The purpose of this report is to compare results from the summer 2005 and winter 2006 monitoring seasons.

National Park Service Natural Sounds Program

The NPS Natural Sounds Program (NSP) Office was established in 2000 to help parks manage sounds in a way that balances access to the park with the expectations of park visitors and the protection of park resources. The NSP addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Directors Orders. An important element of this mission is working with the Federal Aviation Administration (FAA) to implement the National Parks Air Tour Management Act. Congress mandated that FAA and NPS jointly develop Air Tour Management Plans (ATMPs) for more than 106 parks where commercial air tours operate. The program also provides technical assistance to parks in the form of acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments throughout the national park system.

Study Area

Muir Woods National Monument is located in a valley along the central coast of California about 11 miles north of San Francisco and 6.5 miles north of the Golden Gate Bridge. The San Francisco Bay Area is a densely urbanized region and is home to 8 million people. The town of Mill Valley is two miles to the east of Muir Woods with a population of 30,000. The climate is Mediterranean, characterized by warm, dry, summers and cool, wet, winters. This section of the Pacific coast is considered a biological “hot spot” because it hosts a disproportionate share of plant species worldwide, in terms of the number of species and the presence of rare or locally endemic species (Dallman 1998).

The monument itself is 560 acres and bordered on the north and east by Panoramic Highway, close to Coastal Route 1. The monument is also surrounded by Mount Tamalpais State Park. Park facilities include a visitor center, café and gift shop, six miles of boardwalked, paved, and unpaved trails, four wooden bridges spanning Redwood Creek, interpretive displays along the paved path, a parking lot, restrooms, and an outdoor classroom. The acoustic measurements for this study were taken about a mile from the visitor center. In the 2005 fiscal year, MUWO received about 780,430 visitors, 300,000 of whom visited during the summer season.



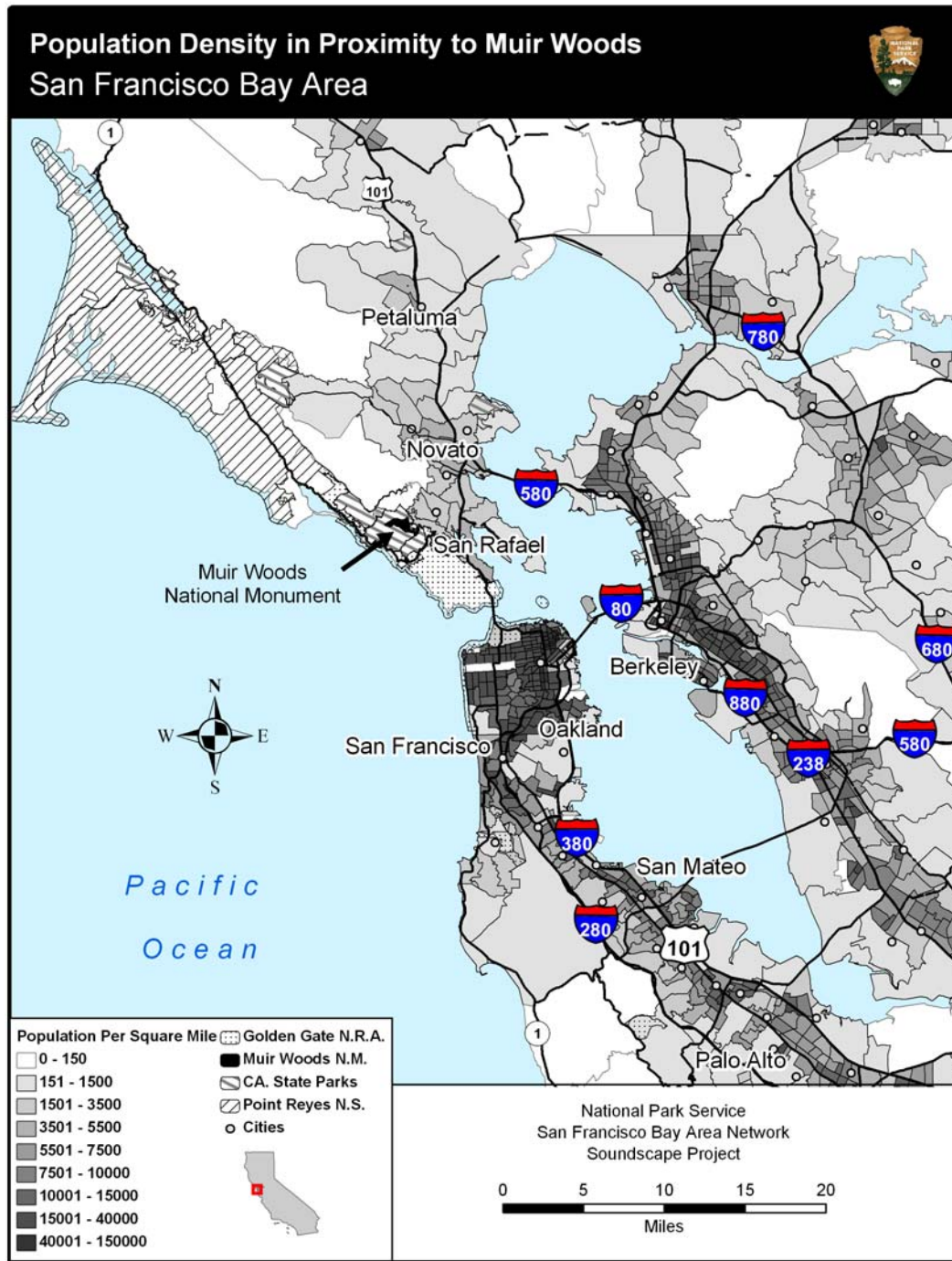


Figure 1. Map showing population density near Muir Woods National Monument.

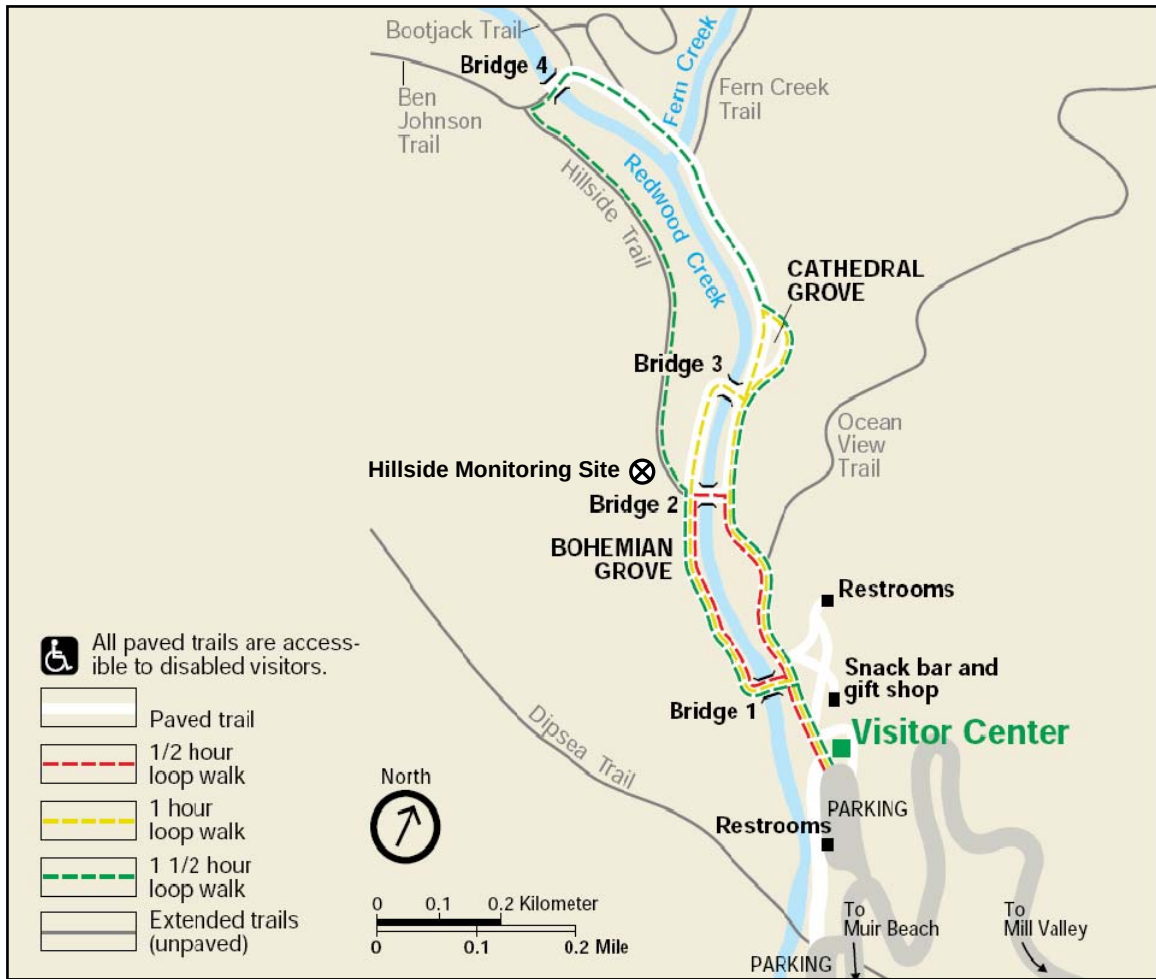


Figure 2. Map showing location of Hillside Monitoring Site.

Description of Monitoring Areas



Figure 3. Photograph of site setup for MUWO001 and MUWO003.

MUWO001 and MUWO003 were set up in the summer of 2005 and the winter of 2006, respectively. They were located off trail, just below the Hillside trail, and near the second bridge crossing over Redwood Creek. These sites were chosen to represent the most abundant habitat in Muir Woods: riparian / old-growth redwood forest.

Equipment, Procedures, & Processing

Measurement Period

To produce existing and natural ambient data with a margin of error less than 3dB at backcountry sampling sites, the National Park Service Natural Sounds Program (NSP) has determined that sound monitors should remain at sampling sites for a minimum of 25 days (NPS, 2005a). Thus, in order to guarantee 25 days of acceptable data, the acoustic sampling stations were left in place for at least 30 days.

Automatic Monitoring

The automatic monitoring at Muir Woods was performed using a Spectra RTA system. SpectraRTA is PC-based real-time analysis software which parses incoming audio signal into 1/3 octave spectrum values, and then utilizes a macro to collect recording samples and sound pressure level (SPL) data. This Spectra -based site met American National Standards Institute (ANSI) Type 1 standards.

Each sampling station consisted of:

- Toughbook PC
- Microphone with environmental shroud
- Preamplifier
- Between three and five 12V gel cell sealed lead acid batteries

For each day of monitoring, a total of 7,200 seconds of digital .wav recordings (sampled at ten seconds every two minutes) were collected. NSP staff then listened to a subset of these samples (eight days or 57,600 seconds per site) and identified sound sources by entering corresponding source codes into a Microsoft Excel spreadsheet. The total percent time extrinsic sounds were audible was then used to calculate the natural ambient sound level. See “Calculation of Metrics.” Bose Quiet Comfort Noise Canceling headphones were used for off-site listening playback to minimize limitations imposed by the office acoustic environment.

On-Site Listening

On-site listening takes full advantage of human binaural hearing capabilities, and most closely matches the experience of park visitors. Logistic constraints prevent comprehensive sampling by this technique, but selective samples of on-site listening provide a basis for relating the results of off-site listening to the probable auditory perception of events by park visitors and wildlife.

Thus, periods of on-site listening were conducted in order to discern the type, timing, and duration of sound events during acoustic monitoring periods at Muir Woods. Staff recorded the beginning and ending times of all audible sound sources using custom-designed Personal Digital Assistant (PDA) software. These on-site listening sessions provided the basis for the calculation of metrics including the period of time between

noise events (average noise free interval [NFI]), percent time each sound source was audible, and maximum, minimum, and mean length (in seconds) of sound source events.

During winter monitoring, protocol for attended logging sessions followed NSP protocol (NPS, 2005a), which states that sessions should begin at the top of an hour and last for one hour. However, this protocol had not been introduced when monitoring occurred during the summer of 2005. Instead, a volunteer-based attended logging protocol was employed. This plan yielded almost 350 15-minute attended logging sessions from five different locations in the park. For the purpose of comparison in this report, attended logging sessions from Curly Bark classroom will be analyzed. This is the site which most closely resembles MUWO001 and MUWO003 in terms of acoustic properties.

Calculation of Metrics

The current status of the acoustic environment can be characterized by spectral measurements, durations, and overall sound levels (intensities). NSP uses descriptive figures and metrics to interpret these characteristics. Two fundamental descriptors are existing and natural ambient sound levels. Existing ambient (L_{50}) is characterized by spectra (in dB) drawn from uncensored data, and encompasses all sound sources. Natural ambient (L_{nat}) is an estimate that attempts to remove all sound energy contributed by extrinsic or anthropogenic noises from the existing ambient. The differences between these two values allow NSP to answer the following questions:

- 1) What are the listening opportunities in the absence of human development and activities?
- 2) How are these listening opportunities compromised by increased sound levels due to noise?

To calculate L_{nat} , NSP does the following:

- Listen to ten second audio samples from eight days of monitoring (about 25% of total monitoring period).
- Identify all extrinsic sounds in each 10 second sample.
- Calculate the percentage of all samples containing extrinsic sounds for each hour of the day (P_H).
- Use P_H to complete this formula for every hour: $x = \frac{1 - P_H}{2} + P_H$
- Example: if extrinsic sounds are audible 50% of the time ($P_H = 0.5$), then x_H is 0.75.
- Enter hourly x_H values into a database of all octave band information.
- Compute L_{nat} (the sound level that is exceeded $100 \cdot x_H$ percent of the time).

This procedure approximates the sound levels that would have been measured in the absence of extrinsic noise. The procedure is guaranteed to produce an estimate that is equal to or below the existing ambient sound level, and the results of this calculation have produced consistent results at most sites.

Percent Listening Area Reduction

The indirect costs of noise resemble air quality issues in that noise limits the auditory horizon just as smog limits the expanse of visibility. A bird misses the sound of a worm, a mouse misses the footfall of a coyote, a visitor misses the babble of a nearby brook: percent listening area reduction quantifies the extent of noise impacts to wildlife resources and visitor experiences.

The maximum distance that a particular sound can be heard depends on its amplitude. But the primary mechanism accounting for the reduction of sound energy as it propagates away from the source is spherical spreading. This assumption is reasonable for most natural sounds that carry a few hundred meters or less when noise is absent.

The general formula for the residual listening area at a monitoring site given a specified increase in ambient sound level (Z in dB) is:

$$\text{Percent Residual Area} = 100(10^{-Z/10}).$$

The following table illustrates the relationship between increased ambient and listening area reduction with some commonly referenced decibel values.

dB ambient increase	3	6	10	20	30	40
Percent Residual Area	50.12%	25.12%	10.00%	1.00%	0.10%	0.01%

This simple formula will overestimate the reduction in listening area for loud sounds that can ordinarily be heard at great distances (several hundred meters or more). This is because other factors reduce the transmission of sound energy: atmospheric absorption of sound energy, interactions of the propagating sound with the ground, the scattering of sound by vegetation, and obstruction of the sound path due to topography. When more accurate assessments are needed for specific classes of sounds, the formula can be amended to incorporate corrections for these effects. However, the more complicated formula is not easily applied to a wide range of sounds, or easily interpreted. Though it is mentioned in the executive summary, this metric had not been fully developed when analysis took place. However, NSP plans to use this metric in future acoustic reports.

Limitations

Audibility

The one-hour on-site logging protocol had not been established when summer logging took place. Thus, comparing 15-minute sessions with one-hour sessions is very challenging. One metric which may have suffered from the 15 minute session length during summer monitoring was noise free interval. In order to generate an accurate NFI calculation, the interval must be bounded on either side by non-natural sounds. However, many of the 15 minute sessions had no extrinsic noise present, resulting in noise free intervals of more than 15 minutes. This suggests that 15 minutes is an inappropriate session length for night and sunrise sessions. Longer sessions are required in order to assure that some extrinsic sounds occur during the logging session. It is very possible that the average NFI calculations for summer monitoring would be greater than the data indicate.

Another limitation of audibility analysis was that the resulting metrics for total percent time extrinsic sounds audible differed between on-site audibility listening sessions and off-site sessions. It should be noted that the on-site listening process sampled a smaller number of seconds of the day than off-site listening (approximately 18,000 seconds versus 57,600 seconds). Furthermore, the on-site listening sessions were generally performed during daylight hours when it was easiest for field personnel to visit the sites, while off-site listening sessions sampled all hours of the day. Therefore, results should not be compared against each other and more weight should be given to off-site listening results.

There was a great deal of variability in aircraft audibility between summer and winter. While the discrepancy between winter and summer audibility is partially due to environmental factors (such as air temperature and presence of leaves) which limit propagation, it should also be noted that the playback equipment used to analyze each season was different. In order to assure continuity between seasons, the two data sets should have been examined with the same headphones and sound cards.

Environmental factors

A small rivulet began to flow by the system mid-way through the winter monitoring period as a result of heavy rains. While the sound of running water is probably an accurate representation of the acoustic environment in the woods, it should be noted that this sound did raise the existing ambient levels at this site and may have masked other sounds that would have otherwise been audible.

Results and Discussion

On-Site Listening

Table 1. Summary of On-Site Listening Results

Site Location	# Sessions	% Time extrinsic sources audible	% Time aircraft audible	Mean noise free interval (min:sec)
MUWO001*	74, 15-minute sessions	42.8	18.0	1:17
MUWO003	5 hour-long sessions	44.5	34.0	2:37

*No hour-long attended logging sessions were performed at MUWO001. The results presented here are from multiple 15 minute sessions at the Curly Bark site in 2005.

As shown in Table 1., there was very little seasonal variation in extrinsic sound audibility during on-site attended logging sessions. During both winter and summer data collection periods, extrinsic sound sources were audible between 42 and 45 percent of the time. However, aircraft were audible about 18 percent of the time in the summer, but were audible (34%) almost twice as often in the winter. Furthermore, the mean noise free interval (period of time during which no extrinsic sounds were audible) was twice as long in the winter. As noted earlier, this could be partially due to different sampling schemes.

Comparing these two sets of on-site attended logging sessions is somewhat problematic because data collection was executed in different ways. For instance, the winter sessions were only performed during daylight hours, while summer sessions were performed during daytime and nighttime hours. Furthermore, during summer sessions, the noise free interval (NFI) could only be a maximum of fifteen minutes long, while the NFI could be up to an hour long in the winter sessions. Despite these discrepancies in data collection, attended logging sessions are still extremely valuable tools for determining the seasonal acoustic characteristics of Muir Woods National Monument. In particular, they are useful instruments for ground-truthing office listening exercises and determining audible sound sources (see Table 2 and Table 3).

Table 2. On-Site Listening Results for MUWO001: Summer.

Sound Source	% Time Audible	Max Event*	Mean Event*	Count Events
Water Sounds	91.2	15:00	02:14	454
People talk/walk (quietly)	49.4	15:00	02:28	223
Bird	44.9	15:00	01:05	462
Vehicle	15.7	07:30	00:46	226
Wind	11.7	15:00	01:37	80
Aircraft, Jet	11.5	05:50	00:44	176
People (loud)	9.2	15:00	00:50	122
Mammal	6.4	07:15	00:23	185
Other, Natural	5.8	14:50	00:22	175
Aircraft, Propeller	5.8	04:21	01:15	51
Motorcycle	3.6	03:40	00:33	74
Non-natural, Other/Unknown	3.3	09:50	00:37	58
Insect	1.9	14:10	00:39	33
Aircraft, Unknown	1.1	01:40	00:38	20
Bus	0.8	01:30	00:24	21
Vehicle - backup beeper	0.6	00:43	00:20	20
Silence	0.4	00:50	00:23	11
Building Sounds	0.3	02:00	01:08	3
Grounds Care	0.3	01:10	00:14	13
Rain/Fog Drip	0.3	01:30	00:13	14
Trash can lid	0.2	01:30	00:09	16
Personal Electronics	0.2	00:20	00:09	17
Aircraft, Helicopter	0.1	00:21	00:21	2
Dog	0.0	00:27	00:27	1
Amphibian	0.0	00:10	00:08	2
Boardwalk	0.0	00:05	00:03	3
All Aircraft	18.0			
All Road Vehicles	19.0			
All Extrinsic Sources	42.8			
All Natural Sources	98.4			
Noise Free Interval		15:01	01:17	497

* Sound events are recorded as minutes: seconds. n= 74, 15-minute sessions.

Table 3. On-Site Listening Results for MUWO003: Winter.

Sound Source	% Time Audible	Max Event*	Mean Event*	Count Events
Water Sounds	99.9	1:00:01**	42:49	7
Bird	28.1	04:32	00:16	313
Aircraft, Jet	26.6	03:35	01:15	64
Wind	9.7	02:55	00:32	54
Aircraft, Propeller	7.5	03:17	01:36	14
People talk/walk (quietly)	6.3	03:58	00:12	94
Grounds Care	6.1	01:39	00:21	52
Vehicle	6.0	01:06	00:18	61
Rain/Fog Drip	0.6	00:15	00:02	60
Non-natural, Other/Unknown	0.5	00:19	00:05	16
Boardwalk	0.3	00:13	00:05	10
Insect	0.2	00:09	00:03	10
Other, Natural	0.1	00:02	00:01	17
Motorcycle	0.1	00:12	00:07	2
Amphibian	0.0	00:01	00:01	2
All Aircraft	34.0			
All Road Vehicles	6.1			
All Extrinsic	44.5			
All Natural Sources	99.9			
Noise Free Interval		06:50	01:04	157

* Sound events are recorded as minutes: seconds. ** Sound events are recorded as hour: minutes: seconds. n= 74, 15-minute sessions.

When Table 2 and Table 3 are compared, the most obvious difference between them is that many more sound sources were audible during the summer. The masking sound of water was far more prevalent in the winter and may have reduced the number of sounds audible near the acoustic monitoring station during this season. With respect to sound sources of interest, people talk/walk quietly was audible 49.4% of the time in the summer and only 6.3% in the winter. In accordance with visitor numbers, vehicle sounds were audible 19% of the time in the summer and only 6.1% during the winter. Interestingly enough, even with the masking sound of flowing water, jets were audible more often in the winter (26.6% versus 11.5 %). In the end, however, the total audibility for all extrinsic sounds was basically the same in summer and winter (42.8% and 44.5%, respectively). These two tables show us that while extrinsic sounds were audible equally as often in summer and winter, what did change between seasons was the number of sound sources contributing to the acoustic environment at Muir Woods National Monument.

Off-Site Listening

MUWO001—Audibility

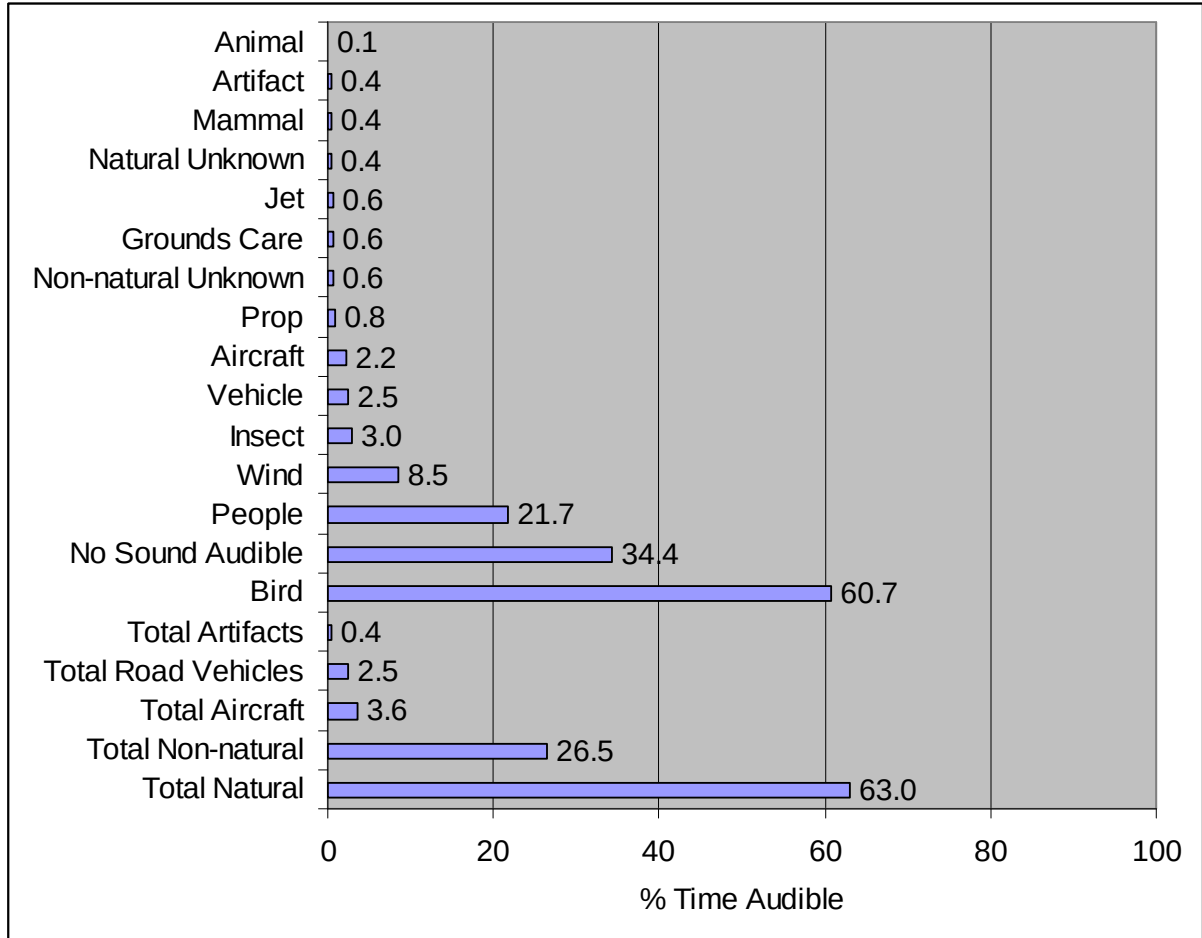


Figure 4. Audible sound sources in off-site listening sessions at MUWO01.

The figure above displays the percent of time during which each sound source was audible in off-site listening sessions. It is interesting to note that “no sound” was audible more than one third of the time during the summer, whereas during the winter, there was always at least one sound source audible. Though the park receives more visitors in the summer, the woods are remarkably quiet in off-peak summer hours because there is very little water running through the park at this time.

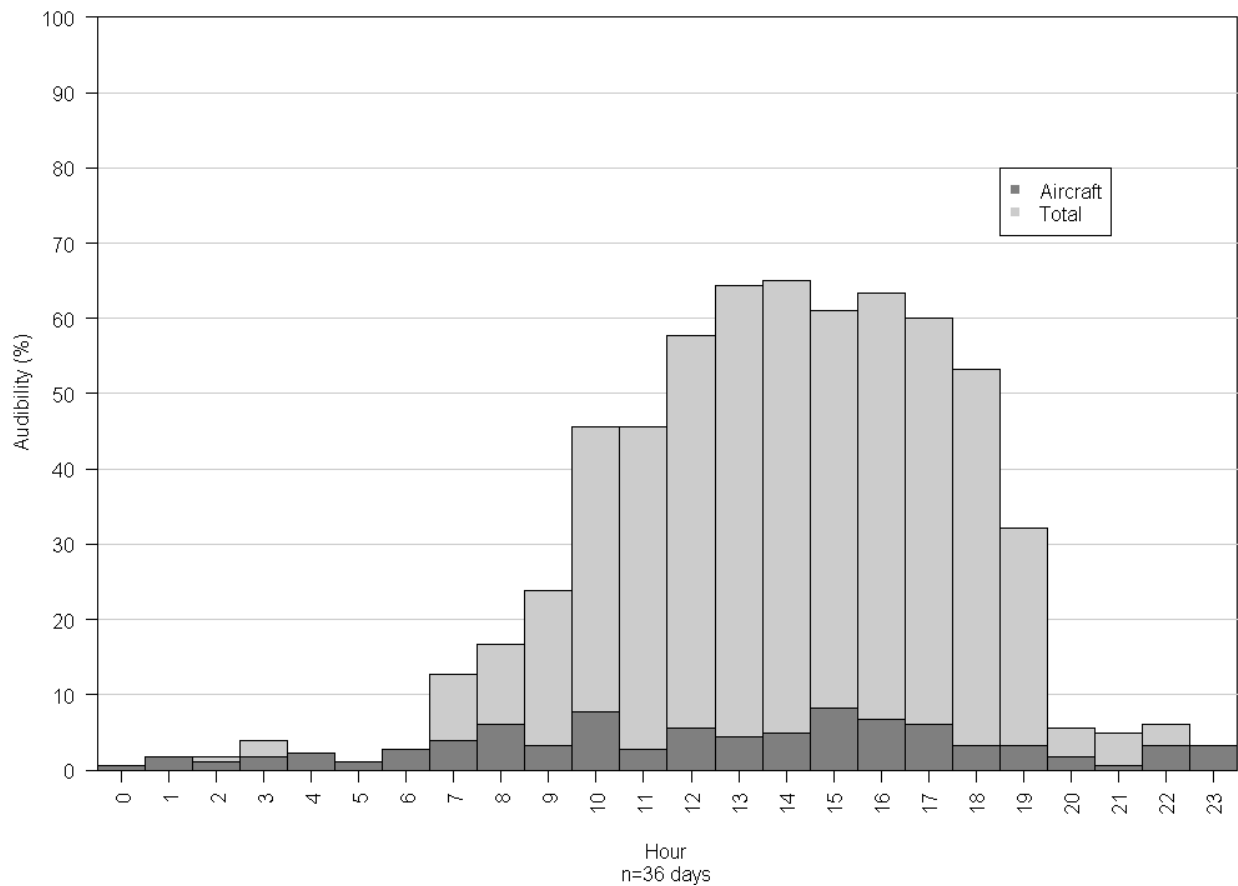


Figure 5. Audibility of extrinsic and aircraft sounds at MUWO001 (Summer 2005). Figure 5 shows the total percent time that extrinsic sounds (light gray) were audible in off-site listening sessions and the percent time that aircraft (dark gray) were audible. The most dominant non-natural sound source was not aircraft but rather, the sound of people walking and talking (21.7%).

MUWO001— Natural Ambient

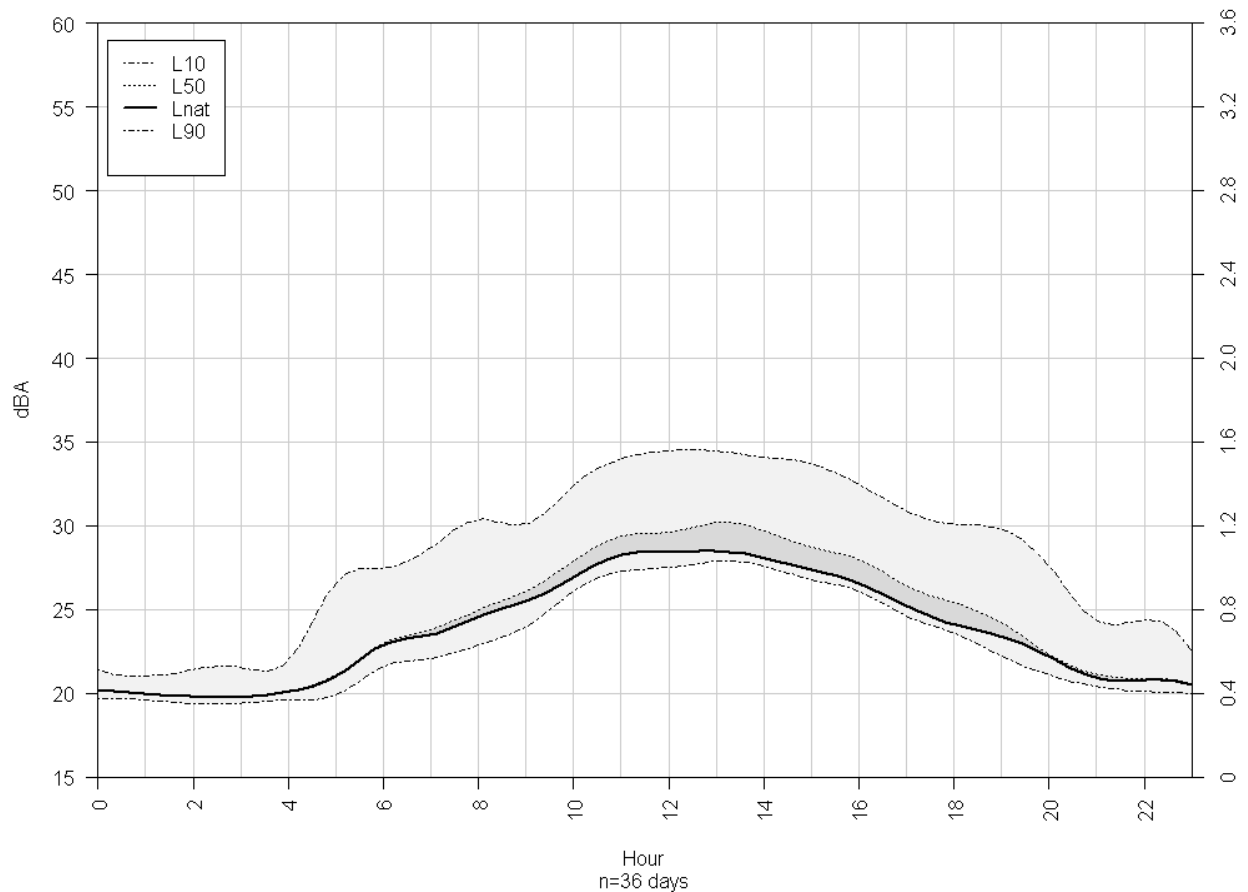


Figure 6. Exceedence values by hour at MUWO001 (Summer 2005).

In the above figure, A-weighted dB metrics are shown as a function of time. A-weighted dB values provide an index of overall sound levels, a weighted sum of sound energy across the audible spectrum. The bold black line is the median L_{nat} , or the median natural ambient. L_{nat} is an estimation of what MUWO001 would sound like without the contribution of extrinsic sound. The dotted line above L_{nat} is L_{50} , or the median existing ambient. Existing ambient includes both intrinsic and extrinsic sounds. L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90} . Median L_{90} is the median dBA value exceeded 90 percent of the time during the sample period. Essentially, it represents the quietest sound levels that occur each hour. Median L_{10} is the median dBA value exceeded 10 percent of the time. It represents the loudest conditions each hour.

Although wind speed measurements were not taken at this site, it seems likely that the rise in ambient sound levels in the middle of the day was caused to some degree by an increase in local wind speed. However, it is also interesting to note that the hours of the day when existing and natural ambient differ most from each other (about 10h00—18h00) are also the hours when human activity was at its peak (see Figure 5). This occurrence suggests that between 10h00 and 18h00, extrinsic sounds raised the natural ambient between 1 and 3 dBA at the measurement site. In the early morning hours, the site was very quiet, and just barely above the 16.5 dBA noise floor limit of the recording equipment.

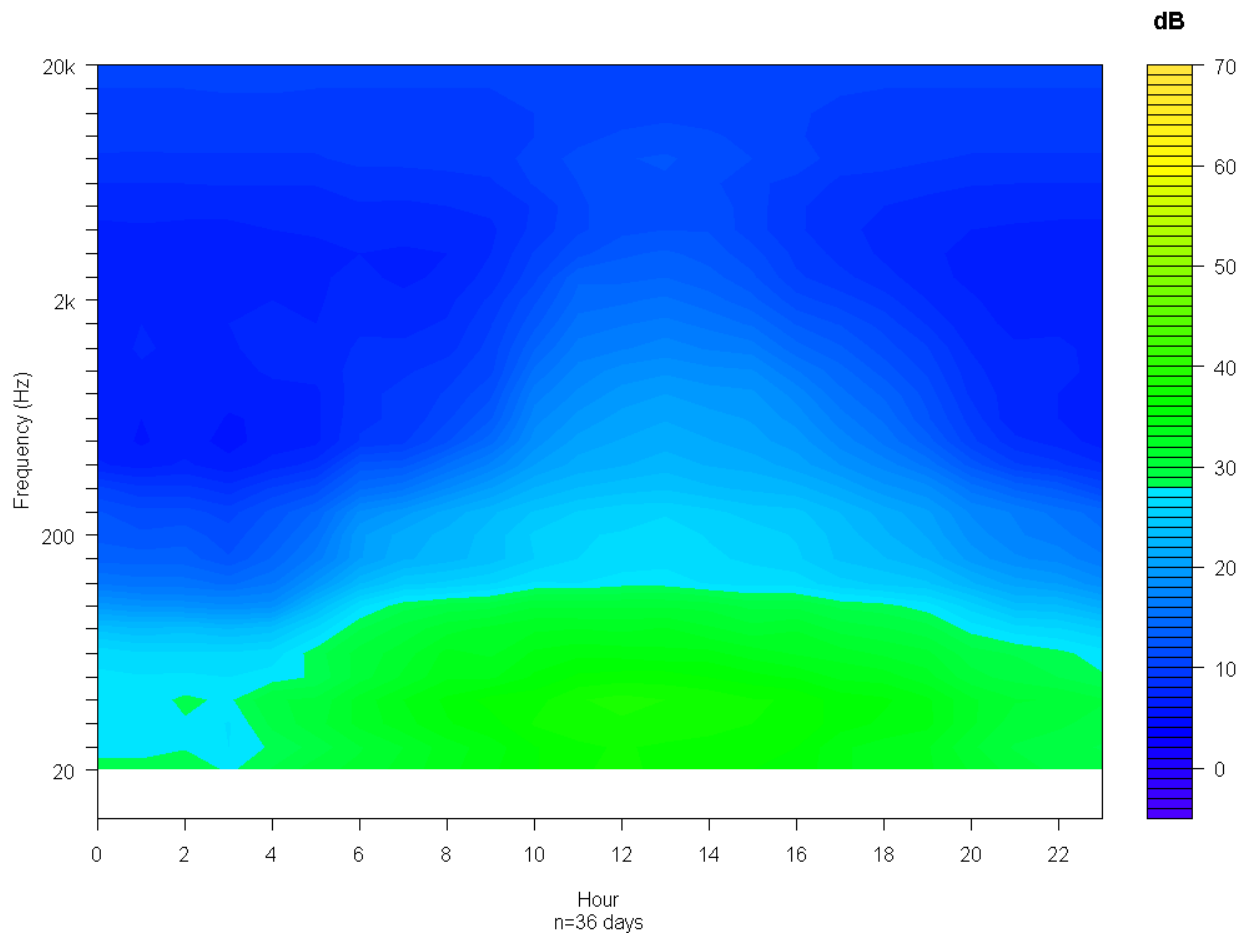


Figure 7. Flat-weighted contour plot of median existing ambient decibel and frequency levels at MUWO001 (Summer 2005) across all hours.

This figure illustrates the variation in existing ambient dB across all frequencies by hour. Darker shades denote lower dB values while lighter shades denote higher dB values. The instrumentation used to collect data at this site measured from 20 Hz to 20 kHz, which is why there is a white band on the contour plot below 20 Hz. This plot suggests that the large majority of sound energy at Muir Woods is focused in the lower frequencies (between 20 Hz and 200 Hz), while the upper frequencies are very quiet. The slight rise in sound pressure level across all frequencies between 10h00 and 18h00 can probably be attributed to the increase in wind speed and extrinsic activity during this part of the day.

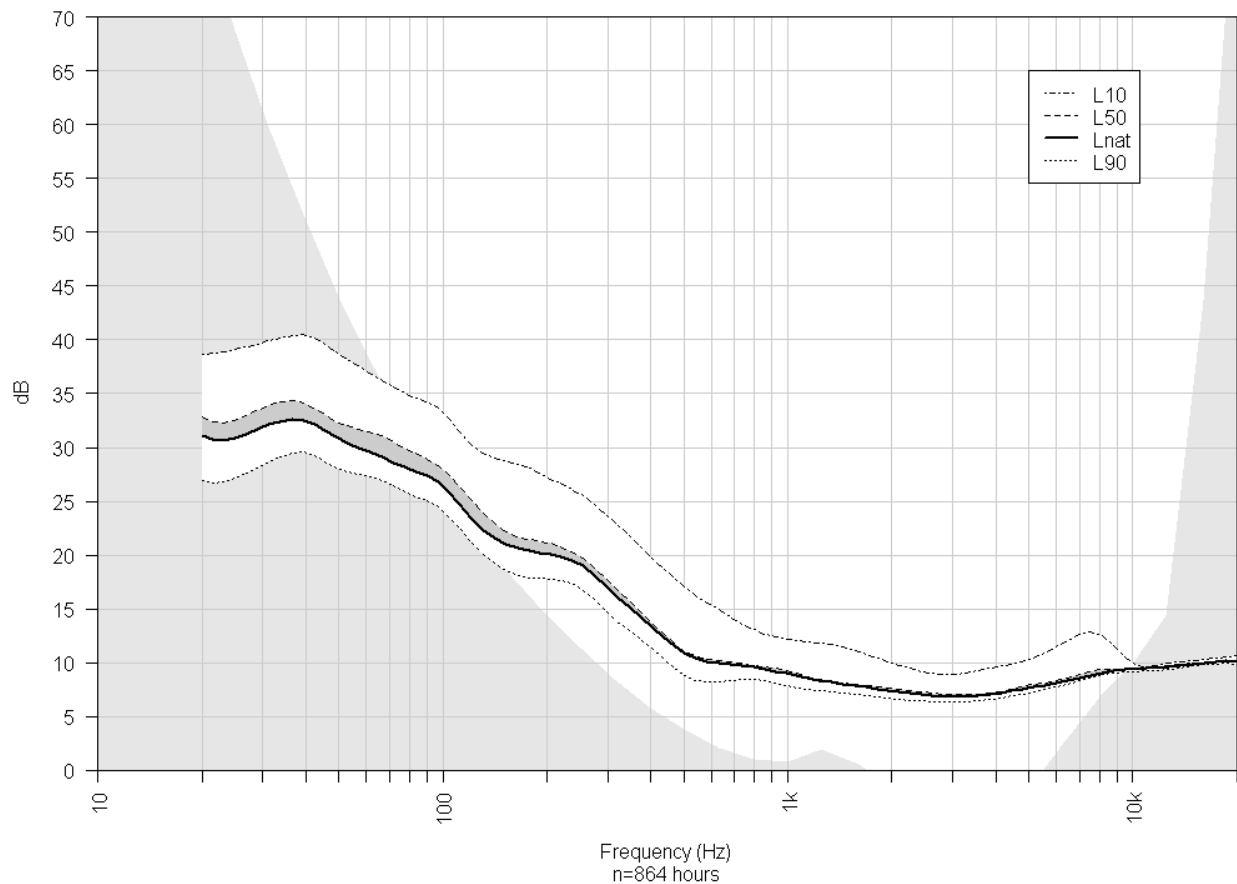


Figure 8. Human threshold of hearing and exceedence values by frequency at MUWO001 (Summer 2005).

This figure plots sound pressure levels on the y axis and frequency (on a logarithmic scale) on the x axis. The threshold of human hearing is represented by the light gray shading in the background. Humans do not hear sounds in the light gray areas. Natural ambient and existing ambient differ most from each other between 100 Hz and 300 Hz, indicating that extrinsic noise is contributing to the existing ambient level at these frequencies. Both wind turbulence and aircraft generate sound at about 125 Hz. Human voices usually generate sound between 300 and 3000 Hz.

MUWO003—Audibility

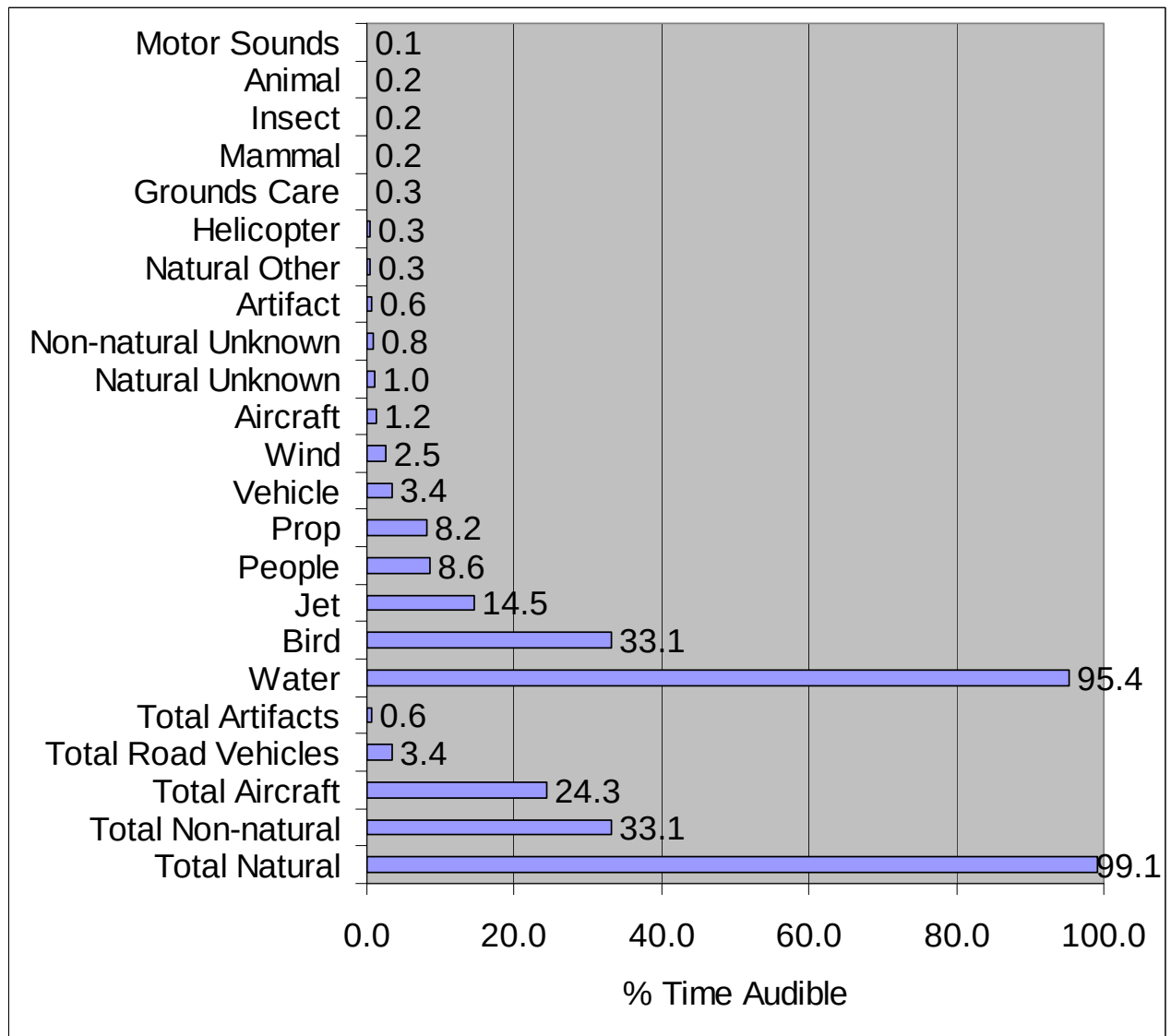


Figure 9. Audible sound sources in off-site listening sessions at MUWO003.

As shown in the above figure, aircraft were heard more often (24.3%) in winter off-site listening sessions than in the summer (3.6%). Water was also an extremely prevalent sound during the winter season at Muir Woods. Flowing water or rain/fog drip were heard almost constantly (95.4%).

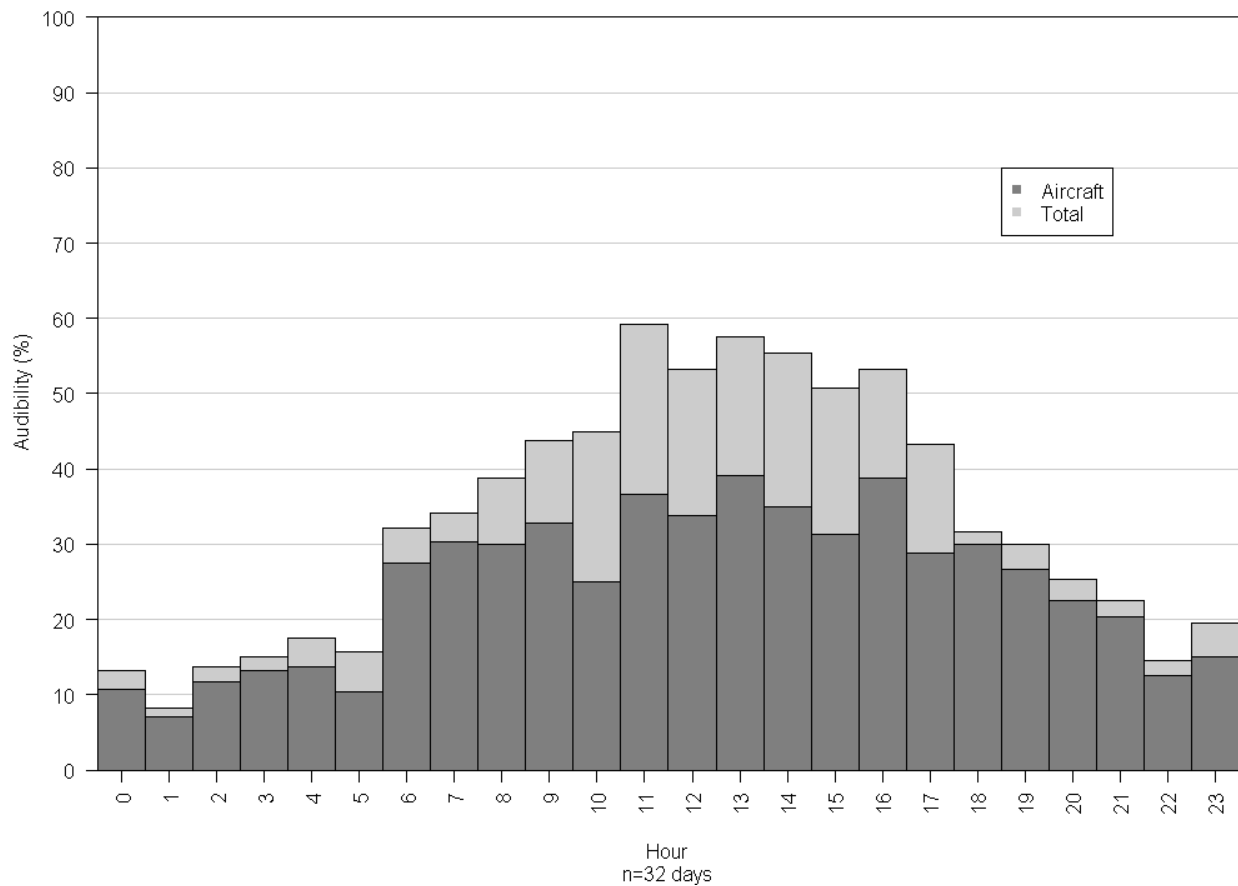


Figure 10. Audibility of extrinsic and aircraft sounds at MUWO003 (Winter 2006). In contrast to MUWO001, it seems that the most dominant extrinsic sound source during the winter monitoring period was aircraft. Furthermore, this figure demonstrates a common aircraft audibility pattern: frequent flights in the mid morning hours (6, 7, 8, and 9), frequent flights in the mid afternoon hours (13, 14, and 15), and relatively few flights in the early morning hours (0, 1, 2, and 3). Other extrinsic sounds which contributed to the total extrinsic audibility included people (8.6%), road vehicles (3.4%), and grounds care (0.3%).

MUWO003—Natural Ambient

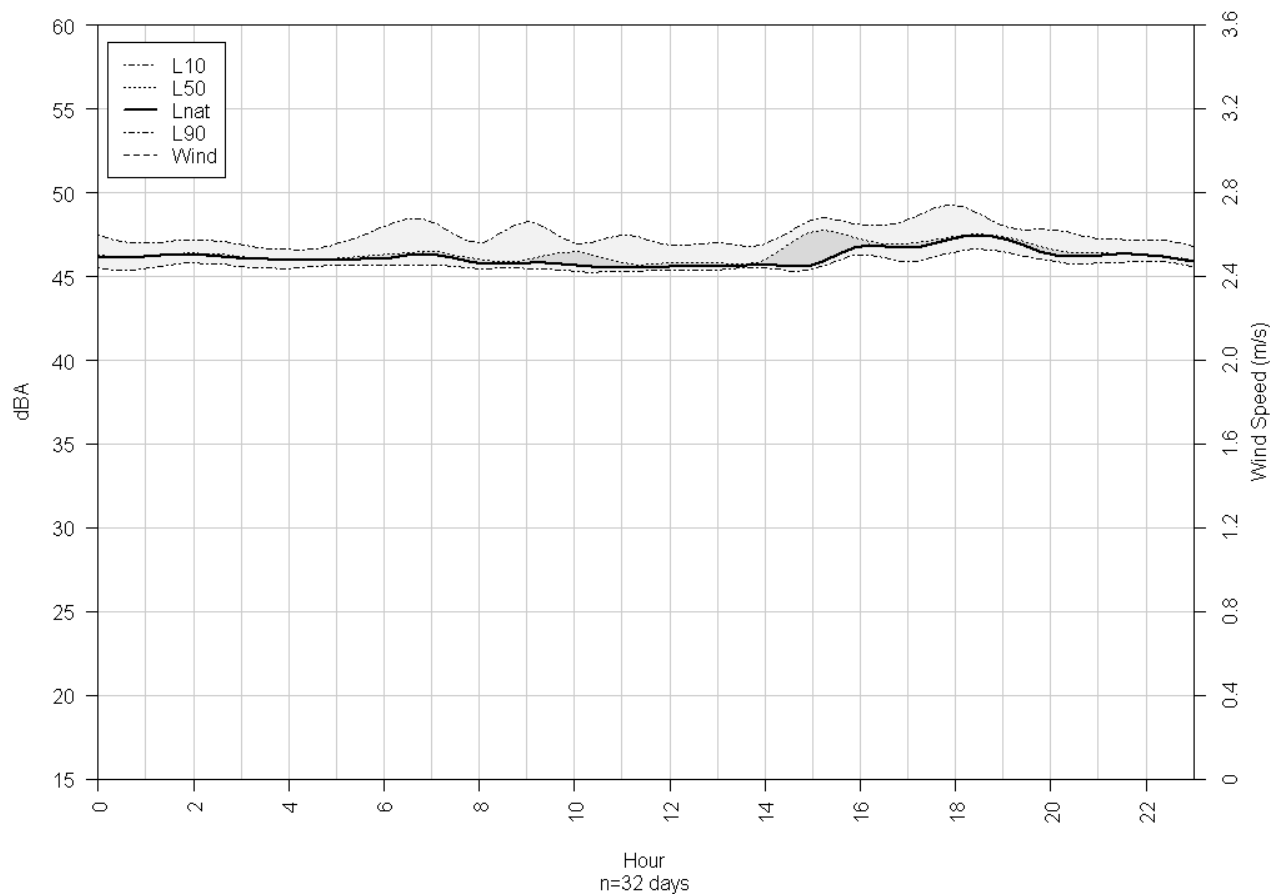


Figure 11. Exceedence values and median wind speed by hour at MUWO003 (Winter 2006).

The natural and existing ambient levels at the winter monitoring site were very consistent. They hovered between 46 dBA and 48 dBA. This consistency is largely due to the influence of the nearby water source. As a result of the steady masking sound of flowing water in the background, ambient sound levels fluctuated very little over the course of the day at this monitoring site.

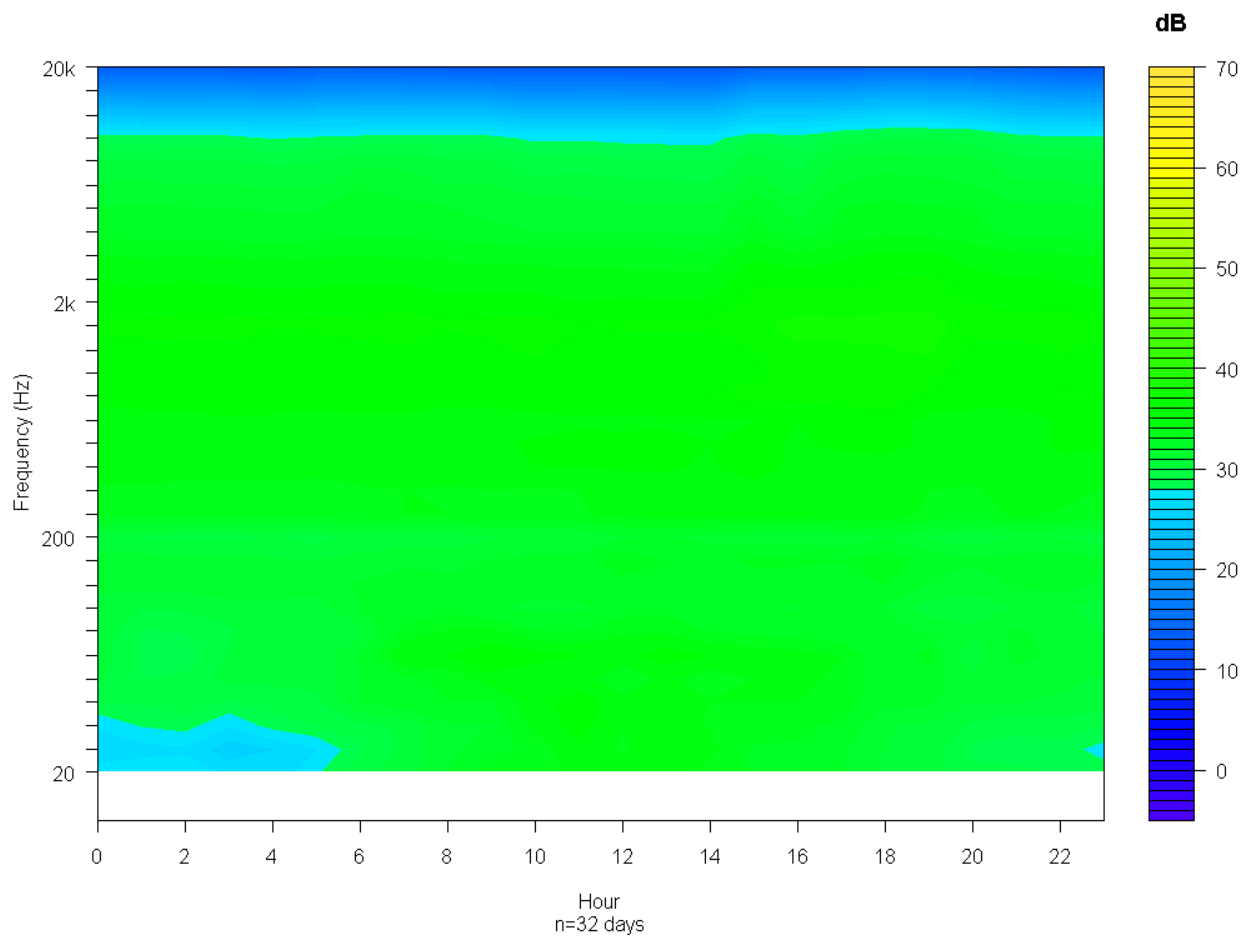


Figure 12. Flat-weighted contour plot of median existing ambient decibel and frequency levels at MUWO003 (Winter 2006) across all hours. This contour plot is typical of a site located near water. There is very little hourly variation in existing ambient because of the persistent sound of flowing water.

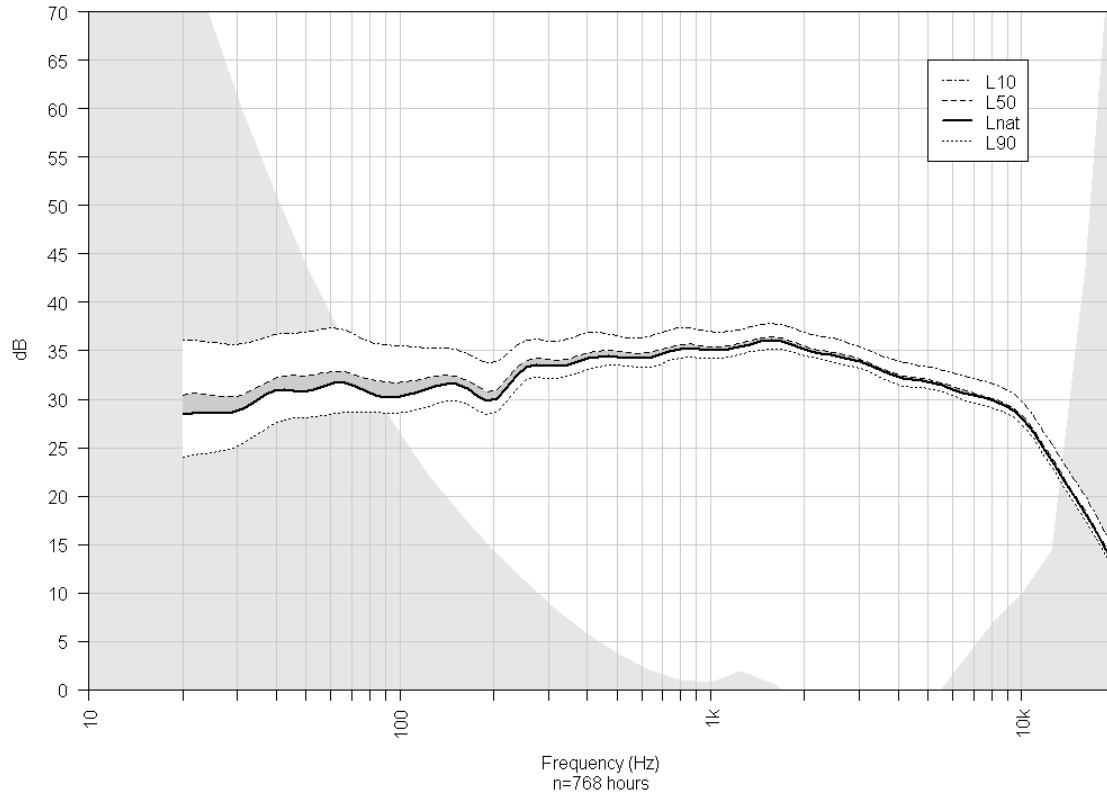


Figure 13. Human threshold of hearing and exceedence values by frequency at MUWO003 (Winter 2006).

This figure is also typical of an acoustic monitoring station near flowing water. Note that whereas the MUWO001 graph drops down in the mid frequencies (see Figure 8), these data points remain high. These are the frequencies where sound is generated by flowing water. As in the MUWO001 graph, the natural and existing ambient differ slightly from each other from 100 Hz to 300 Hz.

Conclusion

Ambient Metrics

The existing ambient levels at the summer site were highest during the day when both extrinsic and intrinsic sounds were most prevalent. During the evening and early morning hours (00h00 to 04h00 and 20h00 to 23h00), this site was very quiet (about 20 dBA) and extrinsic sounds had little effect on the existing ambient. Situated in a densely-forested canyon, this monitoring station was well-protected from wind, allowing the natural and existing ambient to remain low. The attenuating characteristics of the soft ground cover and large redwood trunks also served to quiet this site. However, the winter site did not have the same sort of daily variability. The sound of flowing water was loud enough that extrinsic sound activity had little effect on existing ambient sound levels. The ambient levels at the winter monitoring site remained consistent over the course of the day and evening, hovering around 45 dBA.

Audibility

According to both on- and off-site listening results, aircraft were most often audible during the winter monitoring period (34% vs. 18% onsite, or 24.3% vs. 3.6% off-site). There are a number of factors which probably contributed to this winter/ summer variability in aircraft audibility. First, in the winter months, there is likely to be less diffraction of sound by deciduous leaves. Second, cooler temperatures allow low frequency sounds (such as those generated by planes) to propagate further over the canyon walls. Third, the playback equipment used for winter analysis was superior to that used during summer analysis.

As discussed in the summer report, one of the most commonly heard extrinsic sounds both in winter and summer, other than aircraft, was people (21.7% in summer, 8.6% in winter). Though winter and summer measurements were taken prior to the 2006 visitor survey and accompanying treatments, in a preliminary survey conducted in 2005, more than 70% of visitors rated the sound of “unknown people” and “groups talking” negatively.

Future Monitoring and Adaptive Management

Acoustic monitoring efforts in Muir Woods National Monument yielded valuable results that allow park managers to better understand the existing acoustic environment of the park. For instance, in addition to the percent time audible metrics, off-site analysis of acoustic (.wav) samples unearthed a number of interesting wildlife and natural sound recordings. In the process of listening to eight randomly-selected days for each site, NSP staff located recordings of spotted owls, great horned owls, and barred owls (sometimes at the same time!).

Presumably, if continuous recordings had been collected instead of ten second samples every two minutes, or if a larger subset of samples had been analyzed, these unique sounds might have been discovered more frequently. Biological monitoring with the use of continuous recording acoustic equipment offers many opportunities to extend surveys to places and intervals when it is inconvenient or impossible for observers to be present.

Acoustic monitoring and data storage technology is constantly evolving, and it is not unreasonable to expect that future monitoring efforts at Muir Woods National Monument will incorporate continuous recording units in addition to sound level meters.

Oftentimes, sounds which are not audible in office playback present themselves in attended logging sessions because on-site sessions take full advantage of human binaural hearing capabilities. This was the case with amphibians, which were heard twice during summer on-site listening sessions and twice during winter listening sessions. This particular sound source is of great interest to Muir Woods because frogs (specifically California red-legged frogs) have not been heard in the woods for about 50 years. Additional on-site monitoring with PDAs would help confirm the presence or absence of this and other species of interest. The Natural Sounds Program would gladly provide guidance for developing an attended logging monitoring scheme at Muir Woods.

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Appendix I: Glossary of Acoustic Terms

Acoustic Environment

The composite of all sounds, regardless of audibility, at a particular location.

Acoustic Resources

Sound sources (wildlife, waterfalls, wind, precipitation, historic and cultural sounds), factors that modify sound transmission (vegetation, topography, and atmospheric conditions), and the soundscape perceived by park visitors.

Amplitude

The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

Audibility

The ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, the masking effects of other sound sources, and by the frequency content and amplitude of the sound.

dBA

A-weighted decibel. A-Weighted sum of sound energy across the range of human hearing. Humans do not hear well at very low or very high frequencies. Weighting adjusts for this.

Decibel

A logarithmic measure of acoustic or electrical signals. The formula for computing decibels is: $10(\text{Log}_{10}(\text{sound level}/\text{reference sound level}))$. 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. Conversational speech is about 65 dB.

Diel

A 24-hour period usually consisting of a day and the adjoining night.

Extrinsic Sound

Any sound not forming an essential part of the park unit, or a sound originating from outside the park boundary.

Frequency

The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound/ Wavelength.

Hearing Range (frequency)

By convention, an average, healthy, young person is said to hear frequencies from approximately 20Hz to 20000 Hz.

Hertz

A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz.

Human-Caused Sound

Any sound that is attributable to a human source.

Intrinsic sound

A sound which belongs to a park by its very nature, based on the park unit purposes, values, and establishing legislation. The term “intrinsic sounds” has replaced “natural sounds” in order to incorporate both cultural and historic sounds as part of the acoustic environment of a park.

Listening Horizon

The range or limit of one’s hearing capabilities. Just as smog limits the visual horizon, so noise limits the acoustic horizon.

 L_{eq}

Energy Equivalent Sound Level. The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

 L_x

A metric used to describe acoustic data. It represents the level of sound exceeded x percent of the time during the given measurement period.

Masking

The process by which the threshold of audibility for a sound is raised by the presence of another sound.

Noise-Free Interval

The period of time between noise events (not silence).

Noise

Sound which is unwanted, either because of its effects on humans, its effect on fatigue or malfunction of physical equipment, or its interference with the perception or detection of other sounds (Source: McGraw Hill Dictionary of Scientific and Technical Terms).

Off-site Listening

The systematic identification of sound sources using digital recordings previously collected in the field.

On-site Listening

The systematic identification of sound sources at a specific monitoring site using a personal digital assistant (PDA). Custom PDA software records begin and end times of audible sound sources. These sessions often last for one hour.

Sound

Variations in local pressure that propagate through a medium (e.g. the atmosphere) in space and time.

Soundscape

The acoustic environment at a specific locale, as perceived by park visitors.

Sound Pressure

The difference between instantaneous pressure and local barometric pressure. Measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

Sound Pressure Level (SPL)

A calibrated measure of sound level, expressed in decibels, and referred to an atmospheric standard of 20 micro Pascals.

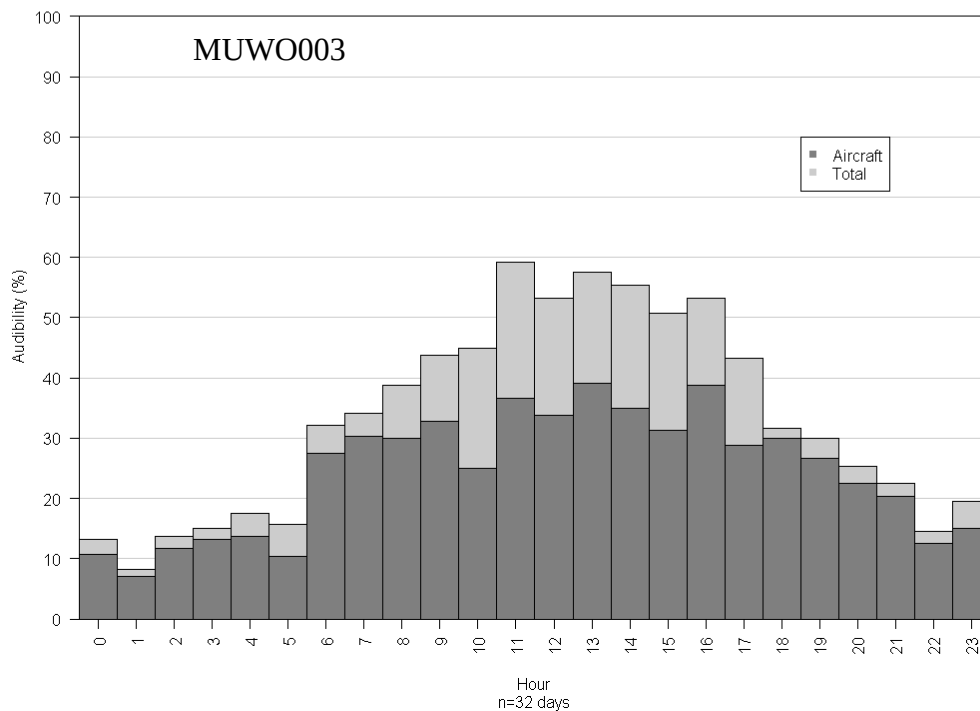
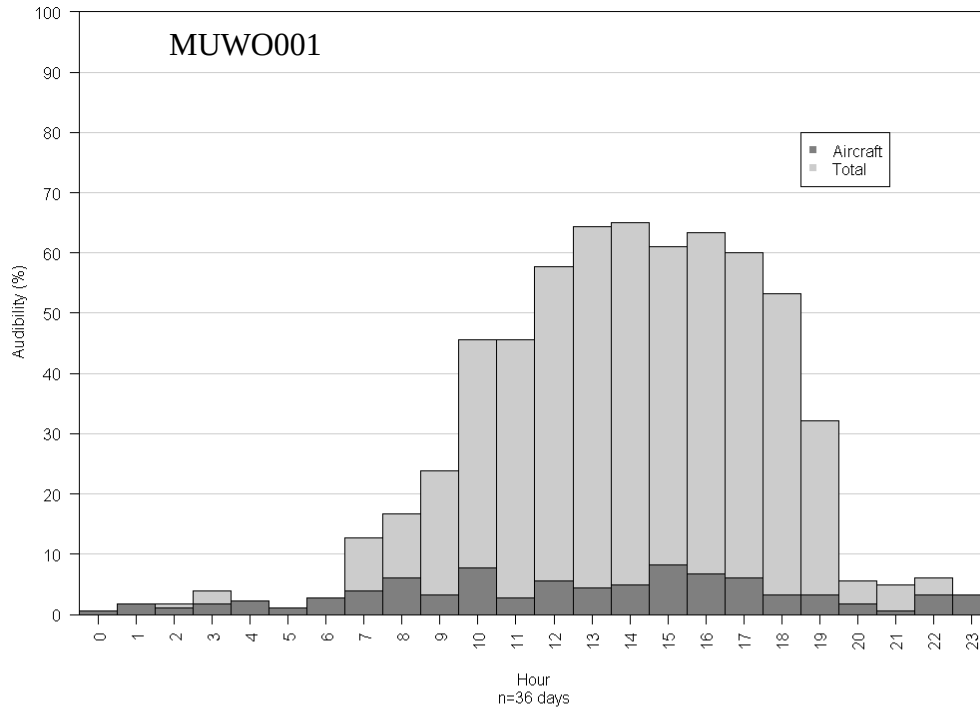
Time Audible

The amount of time that a sound source is audible to an animal with normal hearing.

Appendix II: Natural Sounds Program Sound Code List

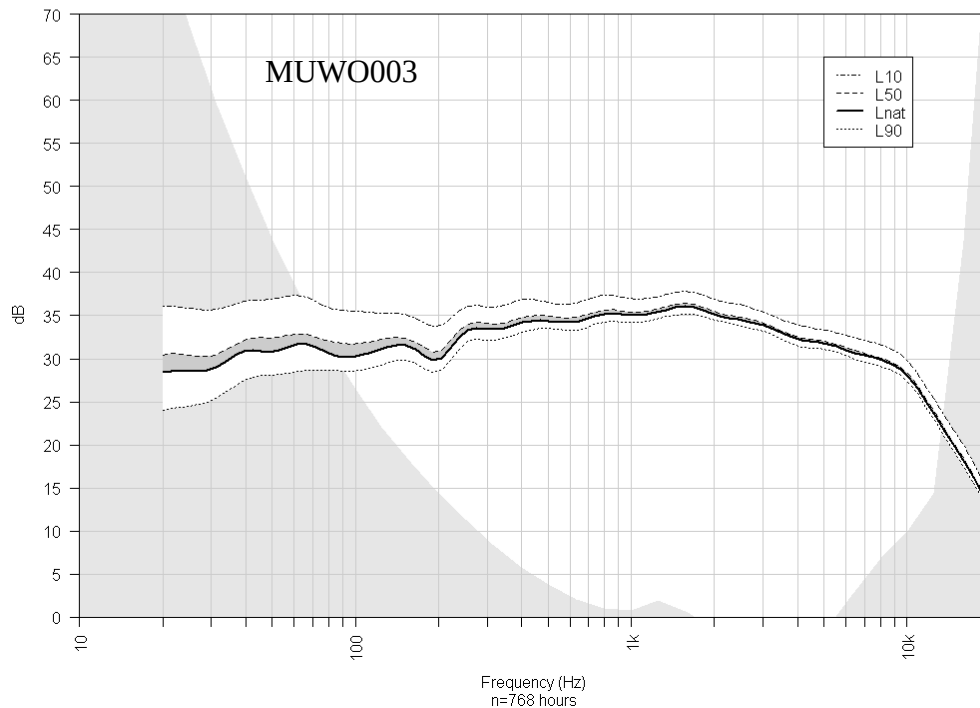
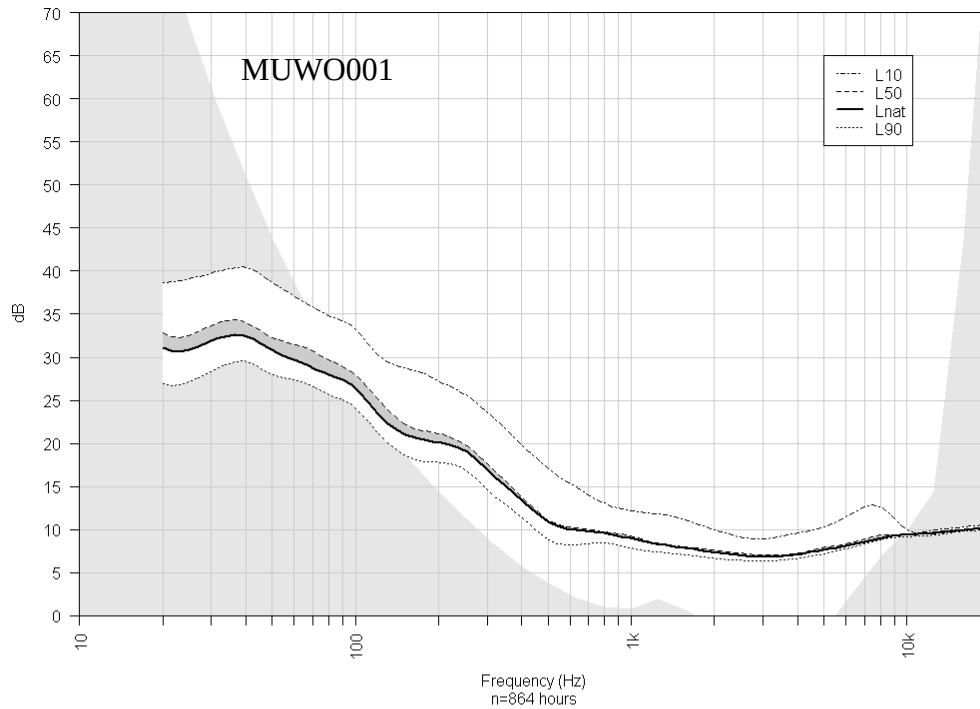
Code	version: 2006-01-13				
0	No Sound Audible	0 No Sound Audible			
41	Artifacts	41 Artifact 41.1 Wind distortion 41.2 Static interference- quiet 41.3 Static interference- loud 41.4 Precipitation 41.5 Field Personnel			
99	Unknown	(Cannot determine if Non-Natural or Natural)			
Code	Non-Natural Sounds Codes (1-20)		Code	Natural Sounds Codes (21-40)	
1	Aircraft	1 Aircraft 1.1 Jet 1.11 Jet, Air Tour 1.12 Jet, Commercial 1.13 Jet, G/A 1.14 Jet, Military 1.2 Prop 1.21 Prop, Air Tour 1.22 Prop, Commercial 1.23 Prop, G/A 1.24 Prop, Military 1.25 Prop, Ultralight 1.3 Helicopter 1.31 Helicopter, Air Tour 1.32 Helicopter, Commercial 1.33 Helicopter, G/A 1.34 Helicopter, Military	21	Wind	21 Wind 21.1 Wind, Light (not mask most other sounds) 21.2 Wind, Strong (masks most other sounds)
2	Vehicles	2 Vehicle 2.1 Automobile (car, van, light truck) 2.2 Motorcycle 2.3 Bus (vehicle with capacity > 9 people) 2.4 Truck (6+ tires) 2.41 Truck Medium (2 ax 6 tire, 10K-26K lbs) 2.42 Truck Heavy (3+ ax 6+ tire, >26K lbs) 2.5 Heavy Equipment 2.6 Rotary Snow Plow 2.7 Other Snow Plow 2.8 RV 2.81 RV < 20 ft 2.82 RV >20 ft 2.9 ATV 2.11 Farm Equipment 2.12 Alarm, Horn 2.13 Door 2.14 Brakes 2.15 Rumble Strip	22	Water	22 Water 22.1 Rain, Fog Drip 22.2 Flowing Water 22.21 Flowing Water, Rapids 22.22 Flowing Water, Riffles 22.3 Snowfall 22.4 Waterfall 22.5 Waves (natural)
3	Watercraft	3 Watercraft 3.1 Outboard 3.11 Outboard 2-stroke 3.12 Outboard 4-stroke 3.13 Outboard Jet Drive 3.2 Inboard 3.21 Inboard 2-stroke 3.22 Inboard 4-stroke 3.23 Inboard Jet Drive 3.3 Jet Ski (PWC) 3.31 Jet Ski 2-stroke 3.32 Jet Ski 4-stroke 3.4 Pontoon Boat/Houseboat 3.41 Pontoon Boat/Houseboat 2-stroke 3.42 Pontoon Boat/Houseboat 4-stroke 3.5 Motorized Raft 3.51 Motorized Raft 2-stroke 3.52 Motorized Raft 4-stroke 3.6 Non-motorized Craft 3.7 Sail Boat 3.8 Boat Wake (on shore) 3.9 Air Boat	23	Thunder	23 Thunder
4	Over-snow Vehicles	4 Oversnow 4.1 Snowmobile 4.11 Snowmobile 2-stroke 4.12 Snowmobile 4-stroke 4.2 Snowcoach 4.3 Snowmobile or Snowcoach 4.4 Snow Groomer 4.5 Snowplane	24	Mammals	24 Mammal 24.1 Squirrel 24.2 Chipmunk 24.3 Coyote 24.4 Wolf 24.5 Elk (pending further revision)
5	Trains	5 Train 5.1 Train Rumble 5.2 Train Whistle	25	Birds	25 Bird 25.1 Raven 25.2 Canada Goose 25.3 Duck 25.4 Gray Jay 25.5 Magpie 25.6 Chickadee (pending further revision)
6	Motors	6 Motor 6.1 Generator 6.2 Pump 6.3 Ice Auger	26	Reptiles	26 Reptile
7	Grounds Care	7 Grounds Care 7.1 Lawnmower 7.2 Leaf Blower 7.3 Sprinkler 7.4 Dumpster / Trashcan	27	Amphibians	27 Amphibian
8	People	8 People 8.1 Voices 8.2 Walking 8.3 Skiing 8.4 Portable Audio Devices 8.5 Gunshot 8.6 Using Boardwalk 8.7 Bicycling 8.8 Segway	28	Insects	28 Insect
9	Domestic animals	9 Domestic animal 9.1 Dog 9.2 Cow 9.3 Horse	29	Animals	29 Animal (Unknown non-human sound from any species in the animal kingdom)
10	Buildings	10 Building Sounds 10.1 Utilities (HVAC, Alarm, etc.) 10.2 Door	30	Geothermal / Mass Movement	30 Geothermal / Mass Movement 30.1 Aval, Rockslide 30.2 Geyser/thermal Activity
11	Construction	11 Construction			
19	Non-natural Other	19 Non-natural Other 19.1 Wind-induced Non-natural	39	Natural Other	39 Natural Other 39.1 Wind-induced Natural
20	Non-natural Unknown	20 Non-natural Unknown	40	Natural Unknown	40 Natural Unknown

Appendix III: Audibility of extrinsic and aircraft sounds by hour at all sites

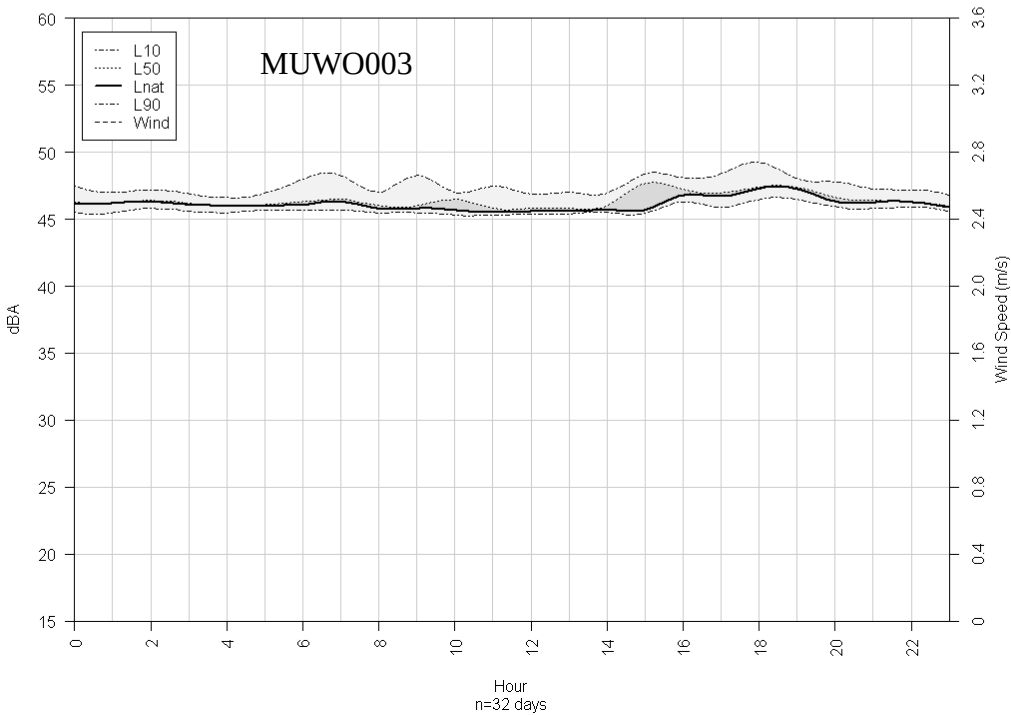
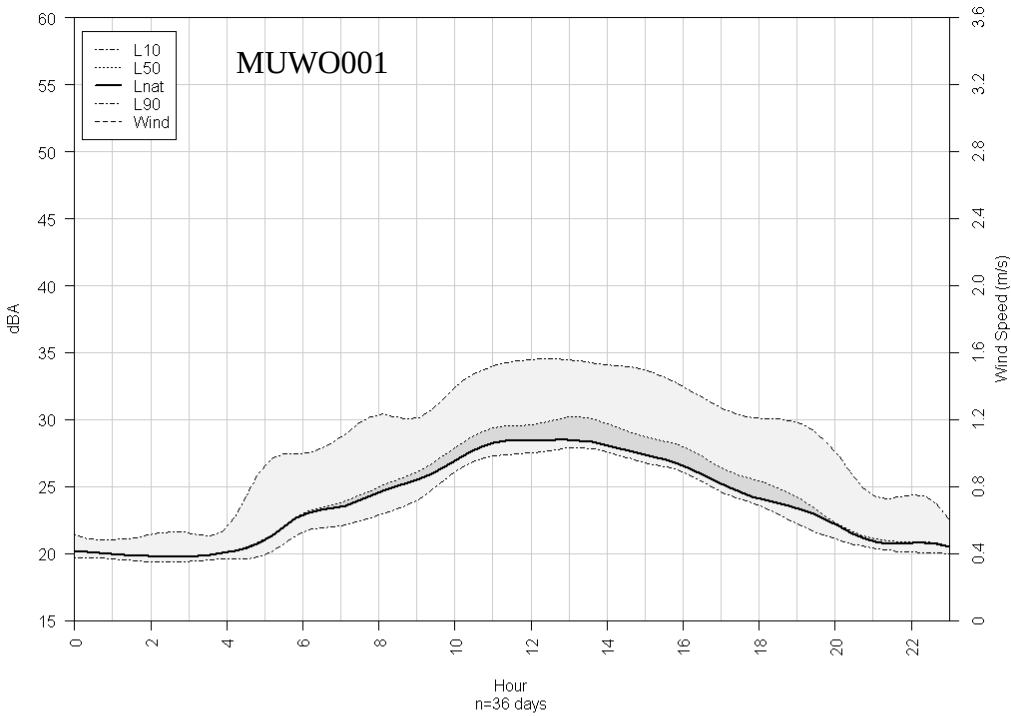


Appendix IV: Exceedence values by frequency at all sites.

(Human threshold of hearing is shaded gray)



Appendix V: Exceedence values and wind speed by hour at all sites



Appendix VI: Flat-weighted contour plots of median existing ambient decibel and frequency levels at all sites

